SpectrumFi, Inc.

December 5, 2016

The Honorable Tom Wheeler, Chairman
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Subject: Suggestions towards the next-generation spectrum sharing ecosystem

[A short summary of the comments]

Spectrum is a critical resource in the today's digital era. To meet the increasing demand for the resource, dynamic spectrum sharing is being investigated. We see the need for enhancing regulations towards dense and real-time spectrum sharing for addressing the business challenges and making the dynamic spectrum paradigm successful in terms of its objectives.

We believe that there exists tremendous potential to dynamic spectrum sharing paradigm. Currently, most of the fine-grained spectrum-access opportunities in the space, time, and frequency dimensions *cannot* be exploited.

From business perspective, the current regulations do not offer the ability to deploy services utilizing the secondary spectrum-access rights in the sub-urban and urban areas. The key obstacles are coverage, performance, and reliability. Recovering and aggregating the fine-grained spectrum-access opportunities poses a great opportunity to deploying services with cost, coverage, reliability, and performance.

Reliability is a key service attribute that requires a lot of technology and regulatory support. Technology could ensure interference avoidance/management/mitigation; however, for the purpose of reliability, it is important to have support to defining and enforcing spectrum-access rights in real-time.

In this letter, we would like to make following suggestions towards developing the next generation spectrum sharing ecosystem that would facilitate to realize maximize the potential of the dynamic spectrum sharing paradigm.

- Under dynamic spectrum sharing wherein multiple heterogeneous spatially overlapping RF-systems are sharing the spectrum-resource in the space, time, and frequency dimensions,
    - We should avoid spatio-temporal-spectral boundaries for RF-systems while articulating the spectrum-access rights; Instead, we suggest to articulate the spectrum-access rights for each of the *individual transceivers* in a quantified manner. We suggest that the granularity of spectrum-access should be an individual transceiver.
    - The granularity of spectrum sharing in the spatial, temporal, and spectral dimensions should be as minimal as possible. This would maximize the recovery and utilization of the spectrum-resource. A few factors influencing the granularity would be the population density and the RF propagation environment characteristics (The spatial rate at which mean path-loss index and shadowing loss vary).
    - The RF propagation environment should be characterized using online spectrum characterization system (SCS). This will eliminate the conservative assumptions often made to handle the worst-case conditions.
    - The spectrum-access system (SAS) should incorporate the position and antenna specifications of the transceivers. This will help to eliminate another set of assumptions that lead to inefficiency in the recovering and exploiting the underutilized spectrum resources.
    - SCS should be applied for recovering the underutilized fine-grained spectrum in the space, time, and frequency dimensions in *real-time*. Having incorporated the knowledge of transceiver attributes and RF-propagation environment conditions, this will enable to maximize the recovery of the unused spectrum.
    - Spectrum-access system should define spectrum-access rights in a quantified manner. This would facilitate *enforcing* the spectrum-access rights, quantifying the harmful interference caused by an individual transceiver, quantifying the aggregate harmful interference received by a single receiver. This could help in defining the regulatory action/penalty.
    - SCS should also be applied for the purpose of enforcing the spectrum-access rights in real-time. This can be accomplished by estimating the spectrum-access parameters of the transmitters in a cochannel interference tolerant manner (for example, exploiting signal cyclostationarity).
- We acknowledge that diverse transceiver specifications complicate the adoption of dynamic spectrum sharing paradigm. Here we draw an analogy to the traffic system which requires certain constraints on the vehicle sizes and suggest to enforce transceiver performance criteria towards shaping future generation of the spectrum sharing ecosystem.

Below we provide extended comments.

[Extended Comments]

CONTENT ORGANIZATION

We begin with highlighting how the technical and regulatory challenges have led to business impediments. We argue that this has been undermining the potential of dynamic spectrum sharing paradigm, we underscore the need for real-time and dense spectrum sharing.

Next, we envision a next-generation spectrum-sharing architecture. Here, we dive into how spectrum is used and suggest an approach for articulating, defining, and enforcing spectrum-access rights in a quantified manner. We make suggestions regarding the regulation enhancements and provide discussion on spectrum technology, spectrum operations, spectrum regulation, and spectrum commerce.

Finally, we acknowledge the complexities brought in due to diverse performance characteristics of the transceivers and make some suggestions towards shaping the future generation of wireless ecosystem.

We include a small set of references that covers many of the arguments contained in this letter. I request you to kindly refer to the references for detailed treatment.

BUSINESS IMPEDIMENTS AND MOTIVATION FOR DENSE, REAL-TIME SPECTRUM SHARING

In terms of articulating the spectrum access rights, the traditional spectrum sharing mechanisms primarily resort to statically or dynamically defining a spatio-temporal boundary along with a fixed set of constraints. In this regard, the case study of dynamic spectrum sharing in UHF bands has brought out several technical, regulatory, and business difficulties.

In Nov. 2008, Federal Communications Commission (FCC) released a Notice of Proposed Rule Making (NPRM) to allow the unlicensed radios to operate in the TV bands without causing harmful interference to the incumbent services. The Opportunistic Spectrum Access (OSA) of the unused UHF bands received a wide commercial interest for several potential wireless services; However, the performance evaluation studies of OSA have revealed that the amount of the implied available spectrum is very limited to meet the increasing demand for RF spectrum. Moreover, the *secondary users cannot ensure desired quality of service necessary for the business cases* due to the secondary rights for accessing the spectrum. On the other hand, incumbents do not have any incentive for sharing the spectrum. Furthermore, the secondary access to the spectrum is very hard to regulate. Considering interference aggregation effects, dynamic nature of propagation conditions, and dynamic spectrum-access scenarios, the primary owners of the spectrum need a way to confirm that their receivers are not subjected to harmful interference and the service experience is not degraded. Furthermore, the behavior of software defined radio devices could be altered with software changes and thus the service is exposed to attacks from the secondary users of the spectrum. In order to ensure protection of the spectrum rights, the spectrum-access constraints need to be *enforceable*.

In the case of emitter-signal detection based secondary access, we observe that the decisions for exercising spectrum-access in case of OSA are based on detection of primary transmitter signal using a certain specified radio sensitivity. In this case, the decision for spectrum-access is binary in nature. This gives rise to 'not enough spectrum for secondary usage' if the policy for shared spectrum-access is conservative and 'no guarantee for ensuring service quality' if the shared spectrum-access policy is aggressive. The binary nature of the spectrum-access decision cannot protect the spectrum rights of incumbents and requires the *spectrum-access policy to be increasingly conservative to guard against interference aggregation*.

In the case of location based secondary access, businesses cannot find opportunity to deploy the services if enough spectrum resource is not available. From business perspective, it is critical to provide service in all the sections of a geographical region. The spectrum resource is usually not available through location based spectrum-sharing in the sub-urban and urban areas wherein there exists a business opportunity even though there exist substantial fine-grained spectrum-access opportunities in the space, time, and frequency dimensions.

Therefore, we need to *avoid imposing spatio-temporal walls* for promoting business cases with secondary spectrum-access.

The questions in Figure-1 enumerate the quantitative decisions involved in the process of investigating the weaknesses of a spectrum sharing mechanism, comparing various algorithms and architectures for recovery and exploitation of the spectrum, and optimizing the spectrum sharing opportunities. Fig. 1. Example questions in case of optimizing a typical dynamic spectrum sharing scenario. The questions shed light on the various quantitative decisions involved with regard to spectrum sharing and spectrum management. The question-map bring out the limitations of existing spectrum sharing methodology to interpret and control the use of spectrum. *If we can characterize and quantify the use of spectrum, it would enable us to effectively manage the use of spectrum.*

When multiple secondary transmitters exercise spectrum-access, we need to quantitatively articulate the spectrum-access rights. This helps maximizing a spectrum-access opportunity without causing harmful interference to incumbents and secondary users. If technical and regulatory problems are solved, more and more incumbents will have an incentive to share the spatially, temporally, and spectrally unexploited spectrum.

Finally, from a business perspective, the ability to qualitatively and quantitatively interpret a spectrum sharing opportunity in a certain frequency band within a geographical region of interest is essential in order to evaluate its business potential. With the change in paradigm, businesses need the ability to precisely control the use of spectrum in order to maximize fine-grained spectrum-reuse opportunities. With spectrum as a quantified resource perspective, the spectrum trade conversation could be on the following lines: "I have 'x' units of spectrum right now, I have given 'y' units of spectrum to somebody and have 'z' units of spare spectrum which I can share". Also, the quantification of the use of spectrum would provide insight into the business implications of a dynamically identified spectrum-access opportunity in terms of the service quality, range, and user experience.

Analyzing the Use of Spectrum

Objective: Maximizing the use of spectrum

- *How much is the opportunity for sharing the spectrum?*
  - How much of the spectrum is underutilized in the space, time, and frequency dimensions?
  - How much of the spectrum could be shared using a certain sharing model?
  - How much of the available-spectrum is rendered inaccessible due to certain conservative assumptions?
- *Is the recovery low?*
  - How much of the available-spectrum is recovered using a certain technique?
  - How much of the available-spectrum is lost due to false positives?
  - How much is the benefit of a certain fusion scheme over another?
  - How much is the impact of lack of knowledge of the propagation conditions on the recovery of the underutilized spectrum?
- *Is the exploitation low?*
  - How much of the spectrum is not exploited? Why?
  - How much is the impact of directional transceivers?
  - How much is the spectrum used by a service? How to maximize the number of satisfied spectrum-accesses?

Defining and Regulating a Dynamic Spectrum-access Policy

- How to dynamically define the spectrum-access rights based on the real-time RF-environment conditions for maximizing the use of spectrum?
- How to quantify violation of the spectrum-access rights occurred for a certain wireless network during a certain time period within a certain region?
- How to quantify violation of the spectrum-access rights by a specific transmitter?

FIGURE 1: There exist several questions when we want to make efficient use of spectrum. We emphasize the limitations of existing spectrum-sharing methodology which cannot easily provide quantitative interpretation of the use of spectrum.

NEXT-GENERATION SPECTRUM SHARING ARCHITECTURE

We envision a next generation spectrum sharing ecosystem and identify requirements for the spectrum sharing architecture.

- The architecture should facilitate defining and enforcing the spectrum-access rights.
- The architecture should facilitate cohabitation of multiple spatially overlapping heterogeneous RF-systems (without causing harmful interference to any receivers in the system).
- The architecture should eliminate conservative assumptions regarding spectrum environment and instead resort to using the real-time spectrum data.
- Dynamic spectrum sharing model forces us to come of the constrained setup and develop dynamic responses to the unknown possibilities in terms of the RF environmental and access conditions. Such dynamic response is possible only via learning the RF-environment and synthesizing behavior, decisions, and actions in advance. The next-generation spectrum sharing architecture should emphasize on learning and adaptation abilities.
- Agile, extensible, and efficient framework that can incorporate diverse spectrum sharing needs. Here, we can consider the spectrum sharing architecture as the meta-container that can accommodate multiple spectrum sharing models.
- The architecture should be easy to adopt for business, spectrum-owners, brokers, and spectrum-operators.

In the next subsections, we present a few perspectives that could be applied towards building the foundation of the next generation spectrum sharing architecture.

A. How is Spectrum Consumed?:

A fundamental question to defining a spectrum sharing architecture is: How is spectrum consumed?

Traditionally, we assume that spectrum is consumed by the transmitters; however, the spectrum is also consumed by the receivers by constraining the RF-power from the other transmitters. We note that for guaranteeing successful reception, protection is traditionally accomplished in terms of the guard-bands, separation distances, and constraints on the operational hours. Thus, the presence of receivers enforces limits on the interference-power in the space, time, and frequency dimensions.When the access to spectrum is exclusive in the space, time, and frequency dimensions, the spectrum consumed by the receivers need not be separately considered.

As we are considering a spectrum sharing architecture for enabling cohabitation of multiple spatially overlapping heterogeneous RF-systems, it is equivalent to considering the entire system as a collection of heterogeneous transceivers. This view essentially eliminates the spatio-temporal-spectral boundaries across RF systems.

B. System Model

We consider a generic system with multiple heterogeneous spatially-overlapping wireless services sharing the RF-spectrum. We define a *RF-link* represents zero or one transmitter and one or more receivers exercising spectrum-access. A *RF-network* represents an aggregate of RF-links. We refer to the aggregate of RF-networks sharing a spectrum space in the time, space, and frequency dimensions within a geographical region of interest as a *RF-system*. We consider that a multiple RF-systems are sharing the spectrum in the time, space, and frequency dimensions within the geographical region of interest. We seek to capture spectrum-access at the lowest granularity. In this regard, RF-link represents the lowest granularity of spectrum-access.

Under the system model, we consider that the transceivers optionally employ directional transmission and reception in order to minimize interference. A receiver can withstand a certain interference when the received Signal to Interference and Noise Ratio (SINR) is greater than a receiver-specific threshold.

C. The Use of Spectrum at a Point

For quantification of spectrum-access opportunity, we identify the minimum and maximum RF-power occupancy. The maximum permissible power (P_{MAX})at any point considering human safety and transceiver engineering limitations. The minimum power at a point (P_{MIN}) in the system could be chosen to be an arbitrary low value well below the thermal noise floor.

- The difference between the maximum and the minimum spectrum consumption at a point represents the maximum spectrum consumption, P_{CMAX}, at a point
- The total RF-power occupied at a point would be governed by the cochannel transmitters. This will be higher than P_{MIN} when there are nonzero transmitters.
- The maximum RF-power that can be occupied at a point would be governed by the cochannel receiver attributes. This will be lower than P_{MAX} when there are nonzero receivers.
- We use the term '*transmitter-occupancy*' to capture the use of spectrum by a single transmitter. We use the term '*receiver-liability*' to capture the use of spectrum by a single receiver. We use the term '*spectrum-opportunity*' to capture the unused/available spectrum at a point. We use the term '*spectrum-occupancy*' to capture spectrum usage by all transmitters at a point. We use the term '*spectrum-liability*' to capture the spectrum usage by all receivers at a point.

Figure 2 illustrates the use of spectrum at a point. It considers an abstract view of the use of spectrum at a single point.

- The total spectrum at a point is determined by the difference between P_{MAX} and P_{MIN}.
- If there are no transmitters and receivers in the system, transmitter-occupancy and receiver liability at this point are zero; the spectrum-opportunity will be maximum, that is, P_{CMAX}. The spectrum-

opportunity represents maximum RF-power that can be used by a future transmitters while ensuring non-harmful interference at the receivers. This scenario is captured by the leftmost bar.

• If we add a pair of transmitter and its receiver, we can observe nonzero transmitter-occupancy and receiver-liability. A key thing to note is receiver-liability being the limit on the maximum RF-power at a point, grows from P_{MAX} towards P_{MIN}. Thus, higher the minimum SINR for successful reception, higher is the receiver-liability. The transmitter occupancy and receiver-liability shape the spectrum-opportunity at a point. The middle bar shows this scenario and we can observe that the spectrum-opportunity has reduced due to the constraint imposed by receiver.

• As more and more transceivers are added in the system, the spectrum-opportunity goes on reducing. This scenario is shown in the rightmost bar. In this case, the spectrum-occupancy captures the aggregate value of the transmitter occupancy from the individual transmitters. With regard to receivers, different receivers impose a different constraint on the RF-power sourced from the point. The effective constraint at this point is determined by the receiver having the highest receiver-liability at the point.

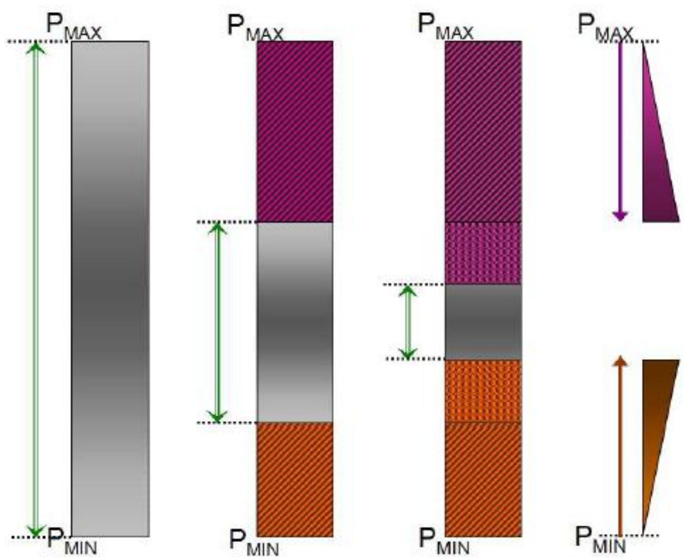

Fig. 2. The use of spectrum at a point. The leftmost bar captures the maximum $(P_{MAX} - P_{MIN})$ spectrum-opportunity (shown with green double arrow) at a point when no transceivers are present. The middle bar shows the spectrum consumed by a transmitter and its receiver. The rightmost bar shows the spectrum consumed by two pairs of transceivers. Here, we note that the spectrum-occupancy grows from P_{MIN} towards P_{MAX} while spectrum-liability representing a constraint on the occupiable RF-power grows from P_{MAX} towards P_{MIN}. The spectrum-opportunity goes on reducing as the transceivers consume more and more of the spectrum at a point.

D. Spectrum-space discretization

The spectrum-space is continuous in the space, time, and frequency dimensions. In order to quantify and characterize the use of spectrum in the space, time, and frequency dimensions, the spectrum-space could be divided in multiple unit spectrum-spaces. Each unit-spectrum-space would denote a unit-region, unit frequency-band, and a unit time-quantum.

Next we apply spectrum-space discretization approach to characterize spectrum-spaces related to spectrum usage and spectrum management. This essentially enables to define and enforce spectrum-access rights in a quantified manner. It also enables to characterize the performance of spectrum management functions (spectrum recovery, spectrum allocation) and optimize spectrum spectrum sharing policies.

E. Characterizing Spectrum Usage

We can identify various spectrum-spaces such as transmitter-consumed spectrum-space, receiver-consumed spectrum-space, utilized spectrum space (aggregate of all transmitter-consumed space), forbidden spectrum-space (aggregate of all receiver's spectrum-space), and available spectrum-space. We can also identify spectrum-spaces specific to certain RF-entities such as RF-system consumed spectrum-space. By applying spectrum-space discretization approach, we can *quantify these spectrum-spaces*.

F. Characterizing Spectrum Management Performance

Spectrum-access policy and technology determine how effectively spectrum gets utilized. We can identify various spectrum-spaces related to spectrum management functions.

A spectrum sharing policy identifies certain available spectrum to be usable-spectrum while it renders remaining as guard-spectrum. A spectrum recovery function may not be to recover all the usable spectrum-space due to false-alarms; it may wrongly recover spectrum-space that is already used due to missed-detections. A spectrum-access mechanism may not be able to exploit all the recovered spectrum-space. With a quantified approach, we can identify, quantify, and characterize all these spectrum-spaces related to spectrum management functions. This is *helpful in terms of spectrum operations* for analysis and optimization of the performance of spectrum management functions.

G. Quantified Spectrum-access rights

If spectrum-access rights could be articulated in a quantified manner, it would be possible to define and enforce spectrum-access policies without imposing spatio-temporal-spectral boundaries.

One of the ways to implement a quantified spectrum-access policy would to be to assign quantified spectrum-access footprints. The spectrum-access footprints could be spatially overlapping. It can ensure cohabitation of multiple heterogeneous RF-systems without causing harmful interference to any of the cochannel receivers.

Quantified spectrum-access footprints would be implemented by a transceiver. When a transmitter is violating the assigned quantified spectrum-access footprint, it could be detected using SCS.

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A quantified approach along with spectrum-space discretization enables us to *control the spectrum usage precisely and flexibly*. It also *facilitates aggregating* spectrum-access opportunities.

DISCUSSION

Spectrum Technology

A quantified approach enables spectrum users to understand how much spectrum is consumed by a single transceiver or any logical collection of the transceivers. It helps to compare, analyze, and optimize the performance of spectrum management functions. For example, it is possible to quantitatively analyze performance of ability to recover the underutilized spectrum of various spectrum sensing algorithms (like energy detection, cyclostationary feature detection) or various cooperative spectrum sensing infrastructures based on the recovered spectrum space, lost-available spectrum space, and potentially-incursed spectrum space.

A quantified approach *facilitates defining and enforcing spectrum-access rights*. A quantified approach provides an agile and extensible framework for realizing diverse spectrum sharing models.

Spectrum-space discretization approach enables aggregating spectrum-access opportunities. It also facilitates learning and adaptation abilities. With the aid of SCS, its possible to develop fine-grained real-time propagation modeling for each of the unit-spectrum-spaces in the geographical region. Its possible to develop connectivity maps as shown in Figure 3. The connectivity map would provide real-time operating picture along with estimate link performance ahead-of-time. This ability would be useful in spectrum assignment, spectrum routing, and ensuring spectrum-link redundancy.

Spectrum Operations

From an operations perspective, Spectrum-space discretization makes it feasible to control the granularity of spectrum sharing. Furthermore, the guard space could be effectively controlled with discretization of spectrum-space. Thus, depending on the user-scenario or depending on the assumptions under the spectrum sharing model, spectrum sharing behavior could be effectively implemented with *precision and efficiency*.

From an operational perspective, learning and adaptation is quite essential for spectrum sharing . It offers the ability to define the spectrum-access rights based on the real-time RF-environment conditions. Using the real-time RF-environment conditions helps to *get rid of the conservative assumptions* (which implies lesser amount of guard-spectrum) and make an efficient use of the spectrum.

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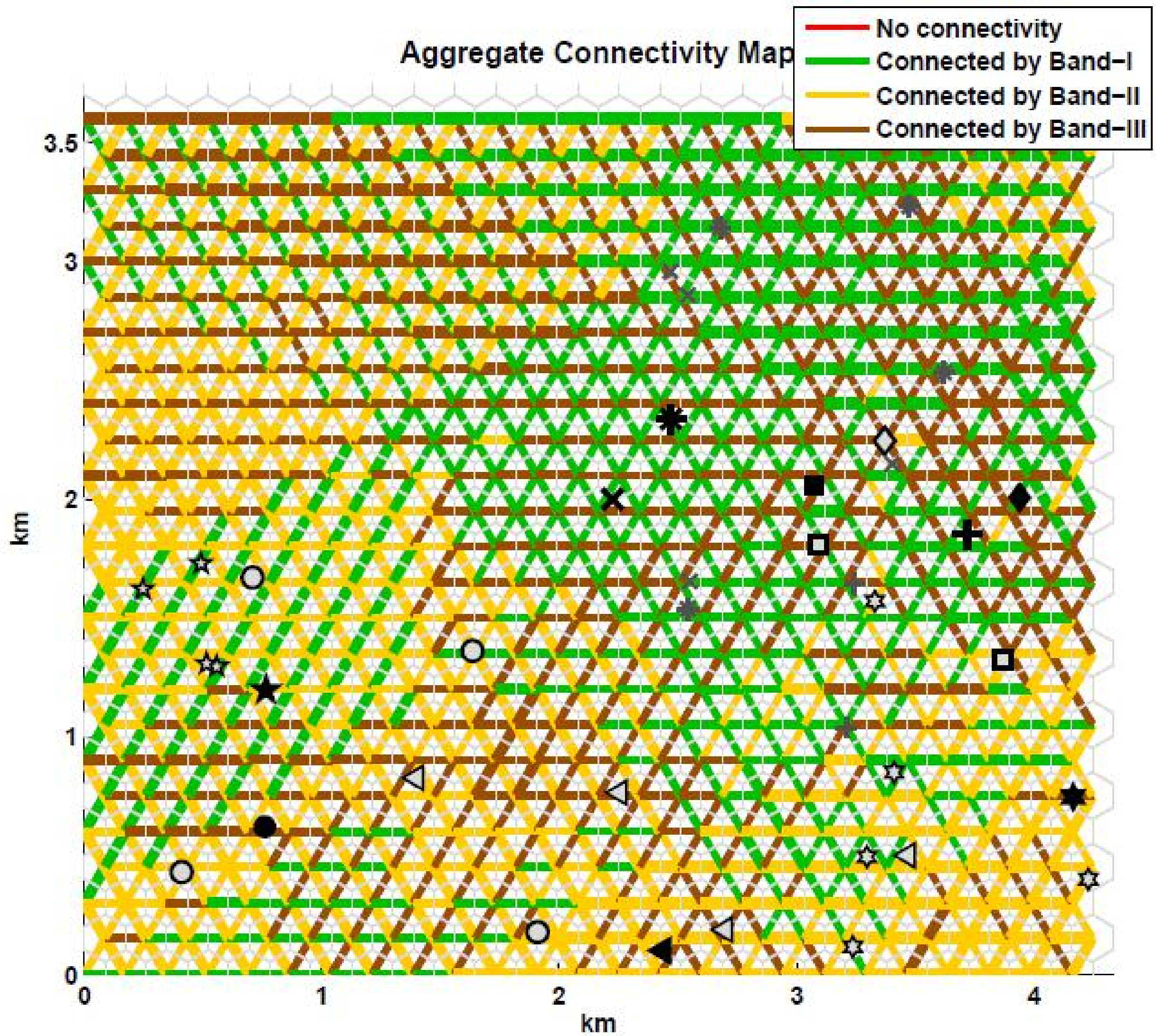

Figure 3. The map shows connectivity between adjacent unit-regions of a geographical regions across multiple frequency bands. Transmitters and receivers in the same network have the same shape; the transmitter is solid. The particular frequency band is encoded through the color of the connecting lines, and the line color is determined by the best available connectivity. The thickness of the link characterizes the potential throughput. The map reveals exploitable spectrum opportunities in the spatial and frequency dimensions. For this particular set of networks, the spectrum-access opportunities within the band I (green), band II (yellow), and band III (brown) are easily discerned. Such fine-grained analysis of the use of spectrum in real time facilitates inferring connectivity, throughput,mobility, C2, surveillance, and warfare.

Spectrum Regulation

The quantified approach facilitates defining and enforcing spectrum-access rights in terms of the use of spectrum by the individual transceivers. This helps to *address the aggregate interference situation*. It is possible to identify the transmitters violating the assigned spectrum-access policy. The quantified approach could be applied in case of diverse spectrum sharing models.

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One of the key requirements for wide adoption of dynamic spectrum sharing paradigm is its enforceability. The quantified approach makes it possible to go towards *automated regulation* of dynamic spectrum sharing.

Spectrum Commerce

We suggest that the key desired parameters for adopting a spectrum sharing architecture are simplicity, precision, and efficiency.

A quantified approach brings in simplicity in spectrum trade. It enables easier understanding and interpretation of the outcomes; thus, it requires less skills of its users. A quantified approach enables to investigate the amount of the spectrum that can shared and evaluate the potential for a business opportunity.

From a business development perspective, spectrum sharing models devised using a quantified approach enable spatial overlap of multiple RF-systems and *avoid spatial fragmentation of coverage*. This is important for defining new services exercising shared spectrum-access rights.

Aggregation of fine-grained spectrum sharing opportunities gives incentives for spectrum-owners to extract more value out of their underutilized spectrum; a bigger spectrum-pool is attractive for secondary users as well. Thus, characterization of the fine-grained spectrum-access opportunities enables building a bigger spectrum-resource pool.

Next, we switch focus to transceivers for the next generation spectrum sharing ecosystem.

NEED FOR ENFORCING TRASCEIVER PERFORMANCE CRITERIA

One of the key challenges for the adoption of dynamic spectrum sharing paradigm is the diverse performance range of the transceivers. It creates significant obstacles in terms of interference management and defining efficient spectrum-access policies. The policy-makers are required to make conservative assumptions to provide protection to the poor quality transceivers. These conservative assumptions undermine the advantages brought in by the new paradigm to the extent that many business cases are rendered impractical.

The situation is analogous to multiple types of vehicles with different sizes sharing a highway without a lane system. This often results into chaos and reduced speeds. We note that imposing constraints on vehicle size makes it feasible to have a traffic lane system and simplify the situation. This analogy could be useful in the design of future generation ecosystem of wireless transceivers.

We would like to make a few suggestions

- Regulatory agencies should consider enforcing interference tolerance criteria on future generation of transceivers.

- We suggest rating receivers based on minimum SINR for successful reception which abstracts the design specifications. Here, receiver technology should not assume fixed transmit-power levels.

- Transmitters need to support to wide-range of transmit-power levels that can enable flexible transmit-power assignments and better facilitate cohabitation.

- As mentioned previously, the lack of knowledge of receiver positions leads to conservative assumptions that can handle the worst-case receiver positions. These conservative assumptions undermine the business potential. Therefore, future generation of wireless receivers should possess ability to directly or indirectly communicate their active time to the ecosystem. (For example, if the device is not internet capable, with short range connectivity, it is possible to have activity notified through a gateway/another device with internet connectivity.)

- When ecosystem is aware of the hardware specifications and activity times of RF-entities, it will be feasible to eliminate several conservative assumptions and maximize the availablity and utilization of the spectrum resource.

- It is clear that the privacy would be an essential element in the design of the next-generation spectrum sharing architecture so that more and more spectrum users are willing to adopt the paradigm.

REFERENCES

In this section, we provide a few references to our published literature that provides more details on technology for quantified approach, spectrum-space discretization, maximizing the availability and utilization of spectrum-resource, defining and enforcing spectrum-access rights in a quantified manner.

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[Concluding Remarks]

We have brought out the business-difficulties when the spectrum-access rights are articulated by enforcing a spatio-temporal-spectral boundaries. We suggest a quantified approach that can articulate the use of spectrum by the individual transceivers in the space, time, and frequency dimensions. A quantified approach makes it possible to precisely control the use of spectrum under spectrum sharing and ensure non-harmful interference among all spectrum sharing networks. Defining and enforcing spectrum-access rights in a quantified manner enables us to maximize the utilization and availability of spectrum and accomplish efficient utilization of the limited resource.

We encourage defining and enforcing spectrum access rights in real-time. Although this requires a dedicated spectrum management infrastructure, it potentially brings in new business models along with flexible and efficient use of the spectrum and an ability for automated regulation of the dynamic spectrum-accesses.

We note that traditionally wireless network services have been conservatively handcrafted to ensure minimum performance under the worst-case conditions. Dynamic spectrum sharing model forces us to come of the constrained setup and develop dynamic responses to the unknown possibilities in terms of the RF environmental and access conditions. Such dynamic response is possible only via learning the RF-environment and synthesizing behavior, decisions, and actions in advance.

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We would be glad to discuss the vision for the next-generation spectrum sharing architecture and the suggestions in more detail.

Respectfully submitted before the Federal Communications Commission. We intend to further the comments to make corrections or additions.

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BIO

Nilesh Khambekar is President and CEO at SpectrumFi, Inc. SpectrumFi solutions bring in simplicity, precision, and efficiency to spectrum-sharing and management. SpectrumFi also collaborates with defense companies regarding development of technologies towards spectrum sharing, spectrum management, and situational awareness.

Nilesh Khambekar is an active participant of standardization bodies related to Dynamic Spectrum Sharing. Nilesh Khambekar is also a researcher and has published works related to spectrum sharing technology and policy in reputed conferences.

Nilesh Khambekar received his PhD from University at Buffalo, SUNY.